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# Evaluation of Water Quality of Cisterns

A.R. Dehghani-sanij[1], M.R. Khani[*2], A. Jalali[2], M. Khani[3], S. Narimannejad[2]

[1] Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL, A1B 3X5, Canada

[2] Department of Environmental Health Engineering, Faculty of Health, Islamic Azad University, Tehran Medical Sciences Branch, Tehran, Iran

[3] Department of Plant Breeding, Faculty of Agricultural Engineering, Islamic Azad University, Karaj Branch, Alborz, Iran

[1]ads485@mun.ca; [*2]mkhani@iautmu.ac.ir

***Abstract***

Collection and storage of rainwater for various purposes, such as drinking, is common in many hot-arid cities and countries. The physiochemical quality of the water of cisterns was investigated. This assessment will provide effective ways to improve the quality of the cisterns' water. In this study, ten villages within the countryside surrounding Lar city were selected and water samples gathered from them are analyzed in regards to physical and chemical parameters. Lar city is a hot-arid region in the Fars province of Iran. Several villages in the surrounding areas of Lar, just like many cities in other provinces, still use cisterns as their main source of fresh water. The primary way in which water gets into these cisterns is rainfall. The results showed that some parameters (i.e., pH, Temperature, Alkalinity, Nitrate, Nitrite, and Turbidity) in the water of all cisterns were at appropriate levels when compared with national drinking water standards. However, other parameters, such as Electrical Conductivity (EC), Total Hardness (TH), Chloride, Sulfate, and Fluoride were not at the desired levels. Generally, the amount of some measured parameters, including Total Dissolved Solids (TDS) and Magnesium hardness was above that found in the normal standard samples. Regarding the geographical location of Lar and the shortage of annual rainfall, the physical and chemical quality of some cisterns sometimes is not suitable. However, provisions can be made to improve the physical and chemical quality of water in the cisterns, leading to a relief of the water shortage problem to some extent and providing higher quality water.

***Keywords***

*Water Quality; Sustainable Development; Rainwater; Cistern*

## Introduction

Throughout human history, water has been understood to be a sacred element and a significant factor in the development of civilization. Although water is the origin of life and prosperity, it can be life threatening as well. Because contaminated water sometimes contains microorganisms and harmful chemical compounds, it should not be consumed. In fact, enhanced public health is closely related to improved water quality. Developed countries effectively tackle the issue of water treatment, whereas the root of many health problems in developing countries is connected to the supply of potable water. The investigation of articles published by the World Health Organization (W.H.O.) is a good indication that the availability of potable water is the most important factor for the health of individual and community. With the growth of population and the advancement of industries, water resources are in danger of pollution more than ever, before. Therefore many countries have adopted some basic standards for drinking water, which vary according to their particular conditions and the degree of industrialization. Likewise, W.H.O. gathered a number of experts and specialists and tasked them to create an international standard for drinking water that can be used within all countries. They did this by reviewing the national standards of many countries around the world.

Due to Iran's geographical conditions and the impact of several other factors, the majority of the land is dry. The amount of rain in Iran is less than one-third of the world average [1-2] and also annual rainfall in the majority of regions in Iran is low [3]. One of the sources of drinking water in most hot-arid cities and countrysides is rainwater. In southern parts of the country, particularly Lar, located in the southeast of the Fars province, rainwater plays an important role in providing the daily water supply for the people. In this area, a common method of water storage

is constructing cisterns with covered roofs of different shapes and sizes (Fig. 1). Normally, rainwater is not chemically polluted and can enter the cisterns. At present, many people living in villages around Lar use water stored in cisterns for drinking, cooking and sometimes washing. Due to rain shortage, cisterns have been used for a long time. In fact, the cistern is one of the most important methods of storing water in hot-arid areas, including Lar. This city, with a 193.22 km$^2$ area and a population of nearly 210000, covers 24% of the province of Fars and has an average annual rainfall of 90-150 mm. The storage of rainwater in cisterns is generally done by collecting water from the roof or yard of the house and all of the surfaces in the surrounding area, and conducting it into the cistern for villages of Lar city.

Dehghani et al. [4-13] used experimental, analytical, numerical, and Artificial Neural Networks (ANN) methods to investigate the thermal stratification of water in cisterns. They filled a cistern in Yazd city on one of the coldest winter days in early January, 2002. Yazd is a city located in the central desert of Iran and has a hot-arid climate. The water in the cistern remained intact until early May. Then, the water was discharged according to the real consumption model until the end of October [4, 6, 10].

FIG. 1 A VIEW OF TWO CISTERNS IN THE VILLAGES OF LAR CITY, FARS PROVINCE

The study revealed that the thermal stratification of the water during the discharging period can be divided into two parts: the distribution of temperature in the lower part is linear, whereas, in the upper part, it is non-linear because of temperature exchange between the upper layers of water with the roof of the cistern, transfer of water mass, and evaporation temperature due to air circulation from wind-catchers. Also, variation of temperature in the lower layer or discharge layer of water during the evacuation period remains between 11.5˚C and 13.1˚C, while the average variation of ambient temperature remains between 23˚C and 38˚C. Hence, during the six months of discharge, when the demand for water was high and the ambient temperature could reach 42˚C, cold drinkable water was available for the residents [4-13]. It should be noted that the temperature of the drinkable water should be between 5˚C and 15˚C, and the best temperature is between 8˚C and 13˚C [14].

In a systematic study of 114 cisterns in rural areas of the Golestan province, where the collected rainwater on the roofs was conducted to cisterns in 1999 (Fig. 2), it was determined that the chemical elements including the ones effective in EC, Alkality, Hardness, Chloride, Nitrate, and Manganese were at acceptable levels when compared with standard drinking water. However, the density of some chemical substances such as Iron (9%), Lead (69%), and Chrome (6%) were higher than the acceptable amount [16, 17].

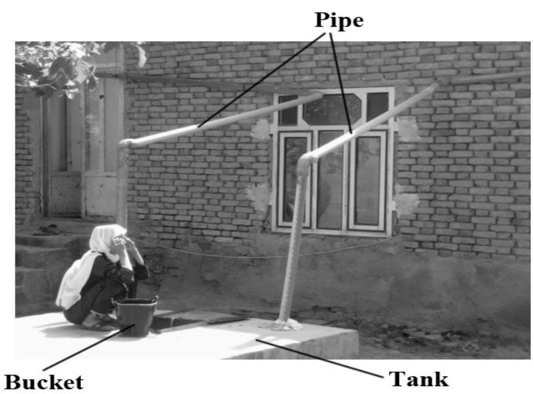


FIG. 2 A CISTERN IN GONBAD-E KAVUS, GOLESTAN, WHICH IS LOCATED UNDER THE HOUSE-YARD AND RAINWATER IS CONDUCTED INTO IT THROUGH WATER PIPES [15]

As a result of the study of microbes in a 100 ml sample of cistern water, the samples Coliform, Escherichia Coli, and Streptococcus Faecalis exhibited higher than standard levels by 56%, 32%, and 26%, respectively. The quality of the water in a considerable number of cisterns, in terms of chemical and microbial elements, was unacceptable. The chemical and microbial contamination of cisterns might be caused by the leaking of agricultural sewage, human and animal waste, and/or river-water following into the cistern [16-17].

In a study by Mohammadi and Shahmansouri [18], the quality of the cisterns' water was investigated in the town of Bandar-e Lengeh. In this study, 60 samples were taken from different cisterns from ten villages over three months. The microbes of samples were analyzed, including Coliform, Escherichia Coli, and Streptococcus Faecalis. The tests were carried out according to the multi-pipe fermentation procedure, differential tests, and the pour plate procedure. The results of the tests have revealed that in 100 ml of the samples, microbial variables such as Coliform, Escherichia Coli, and Streptococcus Faecalis exceeded the maximum acceptable rate in 100% of collected samples. Human and animal feces and other factors are considered to be the most important microbial pollutant. The Chloride residue of the water of all cisterns was reported to be zero.

Microbial, physical, and chemical tests were performed on the water of cisterns in the villages of Sabzevar in Khurasan Razavi province [19]. In microbial tests, variables of Coliform and Escherichia Coli, in physical and chemical tests such as variables of pH, Color, Odor, Turbidity, Alkalinity, Hardness, Chloride, Fluoride, Sulfate, Carbonate, Bicarbonate, Nitrite, and Nitrate were examined. The tests showed that all physical and chemical factors were within the standard limits, except for one of the cisterns in which the Fluoride and Chloride was beyond the limits. The probable reason for this could be the geophysical condition of the soil. The results of the microbial tests indicated that the number of Coliforms in 50% of the samples and that of Escherichia Coli in 40% of the samples were higher than standard levels. The main cause for these higher standard levels is believed to be the microbial pollution of the stored water.

In another investigation by Dehghani et al. [20], they carried out qualitative and quantitative investigations of cisterns' water in the town of Birjand. In this study, 12 samples of water were sent for analysis of chemical parameters, and 9 samples for the microbial analysis were collected from different villages in two stages in April and July of 2009. The results showed that the physical and chemical parameters (i.e., Turbidity, pH, EC, TH, Alkalinity, Chloride, Sulfate, Carbonate, Bicarbonate, Nitrite, Nitrate, Fluoride, Calcium, Magnesium, Sodium, Potassium, Iron, Manganese, Ammoniac, and TDS) in all cisterns were at acceptable levels when compared with drinking-water standards. Only the density of some substances, like Iron, was greater in 16% of the samples, and Fluoride was below the standard level in all samples. In terms of microbial parameters in 100 ml of the samples, the number of Coliforms reached 77% in the probable stage, and 33% in the confirmation state, which was higher than the standard. In 11% of the samples, fecal Coliform was observed. Although the chemical quality of these cisterns was at an acceptable level, but the level of microbes was not.

This study evaluates the water quality in cisterns of the villages in the urban areas of Lar city, which were examined through physiochemical tests in order to find the probable sources of pollution and to propose suitable and practical solutions to removing them and finally to ensure that the water is safe for drinking. Also, this study investigates the role of cisterns in sustainable development and in coping with water shortage.

## Methodology

### *Investigation Process*

In this study, 10 samples of water were randomly collected from 10 different villages of Lar city (Fig. 3): Hourmood Abbasi, Tang-e Assad, Ghallat, Haj Abdol Korsi, Khoneh Ouz, Seyed Kamal Mostafavi, Kholour, Eslam Abbad, Golar and Mohammad Zinar. The samples were subjected to physical and chemical tests. The variables in samples were as follows: Temperature, EC, TDS, Turbidity, pH, Chloride, Sulfate, Fluoride, Bicarbonate, Nitrite, Nitrate, Total Hardness, Alkalinity, Calcium Hardness, Magnesium Hardness, Sodium, Calcium and Magnesium ions. The samples were collected according to the procedure outlined in the standard methods of water and wastewater examinations [21] and were sent to the laboratory of Shiraz Health Center to be quantified. Then, the findings were

analyzed.

***Sampling Procedure***

The samples were obtained at the cisterns according to common procedures. For retrieving water, the measurements of the temperature and pH were carried out on location. Then, samples were collected in special test tubes and secured in a bag (Fig. 4).

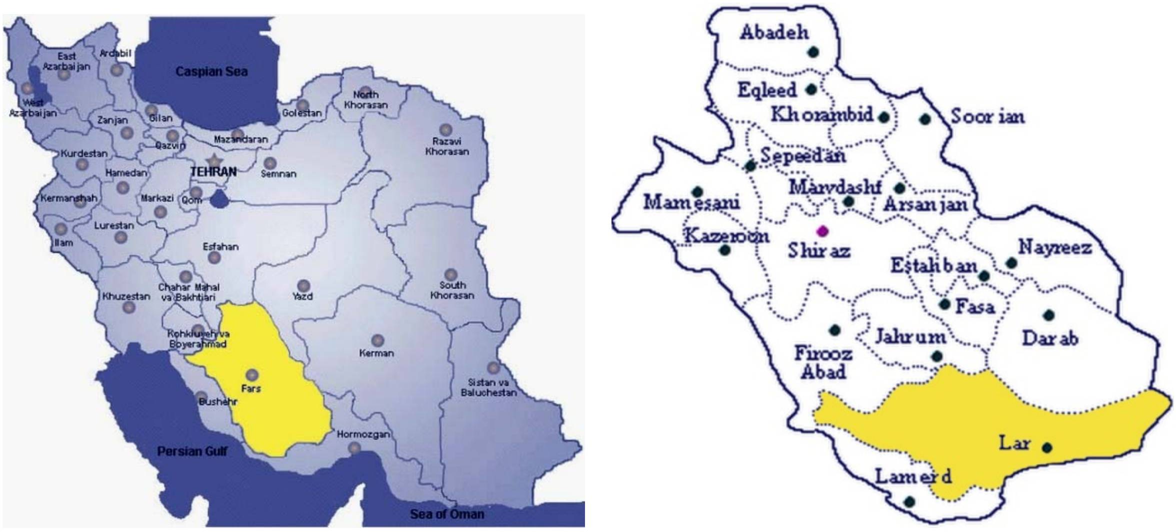


FIG. 3 MAPS OF IRAN, FARS PROVINCE AND LAR CITY

FIG. 4 A PICTURE OF HOW THE WATER SAMPLE WAS COLLECTED

***Testing Procedure and Equipment***

To measure the temperature, a digital thermometer with desirable accuracy was used. To calculate pH, a pH meter, color comparison kit and digital meter with 0.01 accuracy (tolerance) were applied. Hardness was tested through Ethylene-Diamine-Tetraacetic Acid (EDTA) titration. Alkalinity was defined by titration with sulfuric acid. Chloride was determined through the nitrate procedure using the DR-2000 Hatch, and turbidity was determined by Nephelometry.

## Results and Discussion

The obtained averages of the physical and chemical parameters, including temperature, EC, TDS, Turbidity, pH, Chloride, Sulfate, Fluoride, Bicarbonate, Nitrite, Nitrate, TH, Alkalinity, Hardness of Calcium, Hardness of

Magnesium, Sodium, and ions of Magnesium and Calcium, are shown in Table 1.

TABLE 1 RESULTS OF TESTS CARRIED OUT ON THE SAMPLES

| Parameter | Average | Max. observed | Max. allowed |
|---|---|---|---|
| pH | 7.9 | 8.2 | 6.5-8.5 |
| EC | 1604.45 | 5685 | |
| TDS | 1761 | 3641 | 1500 |
| TH | 362.1 | 912 | 500 |
| Total alkalinity | 127.2 | 196 | -- |
| Calcium hardness | 195.1 | 464 | 200 |
| Magnesium hardness | 166.1 | 468 | 150 |
| Calcium ion | 77.99 | 185.6 | 250 |
| Magnesium ion | 40.2 | 112.3 | 50 |
| Sodium | 213.5 | 900 | 200 |
| Chloride | 177.71 | 1233.4 | 400 |
| Nitrite | 0.01451 | 0.05 | 3 |
| Nitrate | 12.7 | 42 | 50 |
| Fluoride | 0.82 | 2.88 | 0.7-1.2 |
| Sulfate | 196.5 | 1060 | 400 |
| Bicarbonate | 152.74 | 239 | -- |

For sampling, 10 villages and one sample from each were chosen.

In the following descriptions, the obtained results of the physical and chemical tests were analysed separately and then compared with W.H.O. standards for potable water.

1) EC: The EC of the samples from 10 cisterns was measured as 320-5316 μmohs/cm. The EC in some cisterns, such as those located in Hourmood Abbasi, Tang-e Assad, and Ghallat were higher, while in other villages (e.g., Haj Abdol Korsi, Khoneh Ouz, Seyed Kamal Mostafavi, Kholour, Eslam Abbad, Golar, and Mohammad Zinar) it fell in the range of less than 500 μmohs/cm. The reason for higher EC in some of the cisterns could be little rainfall in those areas, and also a high evaporation rate is caused by the climate and geographical position of the region.

2) pH: The pH is an indicator of Alkalinity or Acidity of water. The pH variation of the samples is 7.3-8.2, (desirable less than 8).

3) Alkalinity: The Alkalinity is measured on the basis of the amount of calcium carbonate in mg/L. The obtained measurements are in the range of 94-196 mg/L.

4) Total Hardness: The obtained measurements are in the range of 120-912 mg/L of Calcium carbonate.

5) Chloride: The amount of Chloride is in the range of 5-1233.4 mg/L (desirable 250 mg/L).

6) Nitrate: The amount of Nitrate is in the range of 5-43 mg/L, (acceptable limit is 50 mg/L)

7) Nitrite: The amount of Nitrite is in the range of 0-0.041 mg/L, (maximum limit is 3 mg/L).

8) Sulfate: The amount of sulfate is between 6-1060 mg/L (the maximum acceptable is 400 mg/L)

9) Fluoride: The amount of Fluoride is in the range of 0.1-2.88 mg/L (desirable limit 0.7-1.5 mg/L).

10) Turbidity: All the samples had the necessary clarity.

The investigation of physiochemical parameters in 10 villages of Lar city showed that the mean of all parameters in more than 90% of samples was within an acceptable range. Since these sources were not deemed to have any microbial problems, they were determined to not be a significant health hazard if used as a drinkable source of water. The cisterns' water, a good, cheap, available water supply, without advanced treatment technologies and without use of energy for treatment are reasonable sources, special in rural and villages with different position and distance between them [22]. Nevertheless, the cistern water resources may be polluted by microbes. In this case, the water of the cisterns must be disinfected by chlorine (such as simple droplet Chlorine instrument) or other disinfectants, but treatment of chemical and physical parameters was not necessary all the time.

## Conclusion

At present, regarding the water crisis and its consequences, the key to succeess is achieving sustainable development and self-sufficiency in clean water availability. In fact, sustainable growth requires a balance between environment and development. In order to attain this goal, it is extremely important to employ indigenous knowledge and methods. The indigenous expertise has been accumulated through centuries based on the cultural, social, economical, and natural conditions of each region, and it has continually adapted to the changes of these dynamic elements. Moreover, the limitations of the geographical conditions and inaccessibility of remote resources have made the indigenous knowledge and expertise economical. A good example is the cistern, which is a passive cooling system to store cold-water during winter and use it in summer.

There are many places in Iran which have salty water with too many minerals, which makes them unusable for providing drinkable water. Furthermore, in many others, surface water is not available and there is no suitable underground water. Therefore, from the old time, in the marginal areas of deserts and in dry and semi-dry regions of Iran where the water is scarce and it is difficult to get to underground water, there have been great attempts to store water.

The findings of this study confirm the fact that the cisterns' water under investigation was acceptable in terms of physiochemical characteristics (except in some cases, where the amount of Fluoride was less or more than the standards of W.H.O.). If there are ways can be found to remove the agricultural and livestock waste and sewage in villages in a proper manner, the microbial contamination of water may be controlled to a great extent.

Another study showed that this research has the same advantage about cistern water quality. Dillana and Zolan showed that rainwater catchment systems in Micronesia were sampled to assess their bacteriological water quality. They explained that the total Coliform and fecal Coliform bacteria tests were used to evaluate 203 catchments on 10 islands: 57% of the the rainwater catchment systems had no fecal Coliform bacteria, and 61% had less than 10 total Coliform bacteria per 100 ml. Thus, this investigation showed that the rainwater catchment systems were found to provide acceptable water for most areas of Micronesia, but disinfection of this source of water prior to consumption is still highly recommended [23]. In rural Northern Kentucky (USA), rainwater is commonly collected from rooftops and stored in cement block cisterns as one of the sources of drinking water. An average of 600 Coliforms/ml were detected in water samples from the bottoms of the cistern storage tanks. Current US regulations for drinking water quality were discussed; a suggestion was made that fecal Coliform levels may be a more approriate guideline for interpreting the water quality of individually maintained, nonchlorinated, nonpiped water supplies, such as cistern storage systems [24]. The research conducted by Chang et al. [25] in Nacogdoches, Texas studied the runoff quality of water by constructing sixteen wooden structures with two roofs each. The roof runoff was compared to rainwater collected by a wet/dry acid rain collector for the concentrations of eight water quality variables, i.e. $Cu^{2+}$, $Mn^{2+}$, $Pb^{2+}$, $Zn^{2+}$, $Mg^{2+}$, $Al^{3+}$, EC, and pH. This study demonstrated that roofs could be a serious source of nonpoint water pollution. The important parameter was Zn [25]. Simmons et al. investigated water quality in their research by collecting samples from one-hundred and twenty-five domestic roof-collected rainwater supplies in four rural Auckland districts. Samples of cold faucet water were analysed for physicochemical and microbiological determinants, including Zn, Cu, Pb, and bacterial indicator organisms such as heterotrophic plate count, total Coilforms, fecal Coliforms, and Enterococci. This study shows that roof-collected rainwater systems provide potable supplies of relatively poor physicochemical and microbiological quality in the Auckland area [22, 26].

People can take advantage of these cisterns and have the required quality and amount of drinkable water available. At present, many countries of the world, like Iran, are faced with the problem of water shortage. Thus, the modification and renovation of cisterns alongside educational training can lead people to healthier lives. Cistern systems are inexpensive and simple, and there is no need to conduct water from long distances. Cisterns do not require electricity for pumps or any other electrical devices. This means that less energy is consumed throughout the world, and which could reduce the impact of global warming.

Sustainable Development has been defined in Brundland under a collective agreement: Our Common Future.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [22, 27-28]. It is worth mentioning that traditional water structures like Qanats and cisterns are indigenous systems for collecting and using water in hot-arid regions of Iran; hence, they play an important role in sustainable development and reducing the problem of water shortage.

## Suggestions

1) Regarding the findings of this study and similar ones, the following suggestions are proposed:
2) Installation of preventive nets and netted-doors to stop objects or birds from entering cisterns.
3) Since everyone could access cisterns, it is possbible that many kinds of contamination would make water polluted either intentionally or unintentionally. Water should be accessible through water pipes or other simple ways.
4) Improving the condition of the area surrounding cisterns by setting a safe boundary. In addition, these boundaries should be constructed at a safe distance from polluting centers such as sewage absorbing wells.
5) Cleaning of cistern at least once a year.

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